Codes of Processing and Multiple Resources:

Model and Methodology

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Abstract

The current multiple resources methodology (Navon and Gopher, 1979) was employed to test the spatial-verbal distinction in the Wickens (1980, 1984) multiple resources model. Twelve subjects participated in a timesharing experiment in which a verbal memory search task was paired with another verbal and a spatial task. Reaction time and error data were examined and revealed that the verbal-verbal combination was generally performed at greater cost and with more interference than the spatial-verbal one. The results were interpreted as general support for the multiple resources distinction between the two codes of processing.

Codes of Processing and Multiple Resources: Model and Methodology

Of major concern in the study of human performance are the limits of the human information processing system. Over the years, most models of human performance have attributed limitations to a single channel (e.g., Broadbent, 1958) or a single pool of attentional capacity e.g., Kahneman, 1973). A more recent conceptualization is multiple resources theory (Navon and Gopher, 1979) in which a number of independent pools of limited resources are hypothesized to be available for the processing of information. For the purposes of this paper, the terms "capacity" and "resources" will be used interchangeably to refer to a mental commodity used for the processing of information. In timesharing situations, the single capacity or channel models predict interference between tasks whenever the limits of the system are exceeded. The multiple resources approach, however, predicts interference between tasks only when they demand resources in excess of those available from the same pool or pools of resources.

Of particular importance in applying and testing the multiple resources model is the specification of the dimensions along which resources are divided. The most extensive proposals are those made by Wickens (1980, 1984), who has suggested that resources are divided along three dimensions. First, perceptual and central processing operations are posited to require

resources from a different pool than response or motor output operations. Second, modality of input (visual vs. auditory) and output (vocal vs. manual) are proposed as a dimension along which resources are divided. Lastly, and the focus of this investigation, is Wickens' hypothesis that resources are divided on the dimension of codes of processing (spatial vs. verbal). These dimensions are illustrated in Figure 1.

Insert Figure 1 about here

Psychologists have been studying the differences in spatial and verbal processing for some time (Solso, 1979, p. 291 cites work from as early as 1880). One position in particular holds that the differences in the two codes of processing are directly related to asymmetries between the cerebral hemispheres (see Moscovitch, 1979, for a review of this literature). In fact, another resources model relies on the notion that each hemisphere has its own limited pool of resources that cannot be shared with the opposite hemisphere (Friedman and Polson, 1981). This model, while allowing that each hemisphere may be more efficient at some types of processing, does not limit a type of processing to a single hemisphere. Wickens has also used the notion of seperation of hemispheres in his model of task-hemispheric integrity (Wickens, Mountford and Schreiner, 1981). Basically, this model holds that to the degree that two concurrently

performed tasks utilize seperate hemispheres, interference will be minimized. The hemispheric question is not the point at issue here, however. While that question is both interesting and important, the aim of the current investigation is to test the spatial-verbal distinction and not the hemispheric one.

Many investigators (e.g., Baddely and Lieberman, 1980; Brooks, 1968; Geffen, Bradshaw and Nettleton, 1973; Gross, 1972) have studied the differences in spatial and verbal coding, but without the recent multiple resources methodology. The relatively few studies employing this approach have confounded the spatial-verbal dimension with others in the Wickens model (Wickens, Mountford and Schreiner, 1981; Wickens and Sandry, 1982). For example, in the Wickens and Sandry investigation, both verbal and spatial versions of a Sternberg (1969) memory search task were paired with a compensatory tracking task. No statistically significant effect of type of memory search task was found in tracking performance. Wickens and Sandry attributed the lack of an effect to high variability in performance on the spatial version of the Sternberg task. It might also be attributed, however, to the fact that a tracking task might load primarily response-related mechanisms, while the memory searches are likely to load heavily in central processing. Wickens' model predicts that tasks that load these different stages, and thus seperate pools of resources, may be time shared relatively more effectively than two tasks that overlap completely. In the

Wickens et al study, four tasks were used, two spatial and two verbal, but modality of input and output was confounded in the dual task pairings with the codes of processing dimension. Again, this reduces the ability of their investigation to determine the exact cause of the patterns of interference obtained. The aim of the current investigation was to study only the spatial-verbal dimension in central processing by using three memory tasks that are assumed to place their resource demands most heavily in central processing. A verbal memory search task was paired with two other tasks: one that is assumed to be predominately spatial in its demands (spatial-verbal timesharing), and one that is assumed to be predominately verbal in its demands (verbal-verbal timesharing).

The methodology to be used in studying the timesharing efficiency of the two combinations is that proposed by Navon and Gopher (1979). Before going any further, it should be noted that this methodology and the multiple resources conception as a whole have drawn some recent criticism (Navon, 1984, 1985). This will be dealt with later. For now, consider the methodology as it was originally conceptualized. One very important part of the methodology is the manipulation of task difficulties. When two tasks are performed concurrently and draw on the same pool of resources, they are likely to be performed efficiently until their combined demand reaches the limit of that pool. Thus, no trading or interference will be seen between two tasks that share

resources until those resources are exhausted. Crucial to showing that two tasks have common resource demands is making one or both tasks difficult enough to exhaust those resources. In practice, this is often difficult to do and, as Navon (1984) points out, an experimenter can often fall back on the argument that his study failed to show common resources where expected because the limits of that pool had not been reached. To avoid allowing such an argument, difficulty manipulations must be strong enough to show an effect in a single task situation. If single task performance is degraded as a result of the difficulty manipulations, then the investigator can assume that the manipulation exceeded the resources required to maintain performance. Such a demonstration makes it difficult to argue that dual task performance would not also exceed available resources.

Single task performance is also important in its role as a control against which dual task performance may be compared. Generally, the decrement that occurs in the performance in a task when another task is added should be larger if the two tasks compete for common resources. Caution must be exercised, though, in using this decrement as a measure of resource competition. Roediger, Knight and Kantowitz (1977) argue that decrements from single to dual task conditions may be difficult to interpret because of some ambiguity as to exactly what caused the differences. The foundation of their argument is that when

examining only the single to dual task decrement, an investigator cannot be sure whether the decrement was caused by competition for capacity (resources), competition for a strucutre (e.g., visual or response systems), or from an increased demand for executive control in the dual task situation. An effort was made in the current investigation to avoid the structural problems by choosing tasks and procedures carefully. Caution will still be exercised in the interpretation of single to dual task decrements, but this effort should make that analysis more useful.

As a solution, Roediger, Knight, and Kantowitz (1977) urge that the capacity demands of both tasks be manipulated in dual task situations in order to show that variations in capacity demands of one task produce changes in performance of the other. These manipulations of demand in the dual task situation are, in fact, present in the Navon and Gopher (1979) methodology in the form of difficulty manipulations. When difficulty is manipulated in the dual task situation, tasks that compete for a common resource are predicted to interfere with each other while those that draw on seperate resources will not exhibit such a pattern. In dual task situations where resources are being shared it is possible for the manipulation of difficulty in one task to affect performance in both tasks. Note that a subject's strategies regarding allocation of resources to each task may cloud this prediction. This will be discussed below - for the present

assume that each task is being allocated an equal share of the available resources. If performance on one task reflects the manipulation of difficulty in the other, resources are assumed to be shared; this condition is labeled "difficulty sensitivity." The opposite, difficulty insensitivity, is predicted in the case of two tasks that do not share resources. Here, increases in the difficulty of one task are predicted to affect only that task, regardless of subject strategies. Hence, the second task is insensitive to difficulty manipulations in the first. Because seperate pools are being tapped, increasing the resource demand of one task can have no effect on performance in the other task because pools are assumed to be independent, meaning resources cannot be transferred across pools. In this investigation, manipulations of difficulty are expected to affect both tasks in the verbal-verbal combination but not in the spatial-verbal one.

As was pointed out above, care must be taken in making these manipulations of difficulty to control for the effect of subject strategies. Multiple resources theory assumes that a subject has control over the manner in which resources are allocated. Given that tasks A and B share the same resource pool, it is entirely possible within the multiple resources conception that a subject might allow performance on task A to fail while holding performance on task B relatively constant as A's difficulty is increased. It would be expected that the decrements in A's performance would be larger than in single task because of the

addition of task B, but B's performance would remain insensitive to manipulations of A's difficulty - a direct contrast to the prediction made above given the situation in which the subject treats each task equally. As one might expect, uncertainty as to just what strategy a subject employed during task performance would raise serious questions for the interpretation of difficulty manipulations.

In order to address such problems, Navon and Gopher (1979) recommend manipulations of task priority accompanied by payoffs that are weighted to encourage and reflect those priorities. For instance, the experimenter might ask the subject to allocate 75% attention to task A and 25% to task B, vice versa, or 50% to each. Payoffs are formed in proportion to these priorities and are based on actual task performance. If these manipulations have their desired effects, clearer conlusions may be drawn from manipulations of difficulty. The priority manipulation also serves as an additional test of resource interference. If two tasks share a common pool, then resource allocation instructions should affect performance of both tasks, demonstrating a so-called trading relationship between them. No effect of emphasis instruction is expected in the case of two tasks that do not share resources. Again, this emphasis or priority insensitivity is expected because seperate pools are assumed to be independent and unable to transfer resources. In the current study, trading of resources is predicted to occur in a verbal-verbal

combination, but not in a verbal-spatial one.

Some very specific predictions arise from the above discussion. The verbal search task will be common to both the verbal-verbal and the verbal-spatial combinations, so it is the primary source of data. Generally, performance on this task should be more affected in combination with the other verbal task than with the spatial task. Specifically, manipulations of difficulty and of priority should produce more effect on the search task's performance when it is combined with the other verbal task. Decrement from single to dual task conditions should also be greater in the verbal-verbal case than in the verbal-spatial one. In the other tasks, the effect of priority and difficulty of the search task should be reflected only in the verbal task, not in the spatial one.

Method

Subjects

Subjects were twelve right-handed males recruited from the general population of Wright State University. They were paid $4.00 per hour plus bonuses available for performance and for completion of the experiment. In all, each subject had the potential to earn nearly $60.00. Subjects also had the option to replace up to 3 hours of pay with extra course credit in introductory psychology if they were enrolled in such a course.

The decision to use only right handed male subjects was based on evidence that showed this group to be the most

consistent in lateralization of function (Levy and Reid, 1978). Given at least some evidence that ties the different codes of processing to seperate hemispheres, it was felt that consistency in the subject population was necessary in this respect. To insure that the volunteers were right handed, a handedness testing procedure was used to screen potential subjects. The test consisted of 15 hand preference questions adapted from Raczkowski, Kalat, and Nebes (1973) and 5 motor tests adapted from Thomas and Campos (1978). Each question on the questionnaire had a value of one point while each motor test had value of two points, one from a prediction by the subject of which hand would be associated with the best performance and the other from the actual performance results. In all, combined questionnaire and performance scores ranged from -25 to 25, the positive number being associated with a high degree of right handedness. Only those volunteers who met a composite score of 20 were employed as subjects. A score of 20 was selected as a criterion in keeping with the methodology of another investigation that employed a similar technique (Friedman, Polson, Dafoe and Gaskill, 1982). As a final screening device, the experimenter monitored the volunteers' writing posture as they filled out the questionnaire. Only volunteers with a normal writing posture were used. Levy and Reid (1976) provide data that show that an inverted posture indicates hemispheric dominance on the side ipsilateral to the writing hand - exactly

opposite of the normal relationship between dominant hand and dominant hemisphere.

Apparatus

Experimental tasks were controlled by a Commodore VIC 20 computer with expanded memory and appeared on a 12 inch black and white monitor. The subject was seated at a table with the monitor approximately 40 cm in front of him. A four-button response pad used for the memory tasks was positioned at a comfortable distance in front of the subject's right hand. The middle two of the four buttons were used for responding, one was labeled "Y" and one "N."

Tasks and Stimuli

Three memory tasks were used, two predominately verbally coded and one predominately spatially coded; these are illustrated in Figure 2. One of the verbal tasks and the spatial task required that the subject hold information over a retention interval for comparison with a test stimulus. These two tasks will be referred to as the "main tasks" from this point on. The other verbal task, a Sternberg (1969) memory search procedure, was used to fill these retention intervals.

Insert figure 2 about here

The verbal main task required subjects to remember a list of either 4 or 8 words over the retention interval. Since words

were used as the memory stimuli, it is assumed that this task is primarily verbal in its central processing demands. List size represents the manipulation of difficulty for this task. The test stimulus was a pair of words from the list; the subject indicated whether or not they were in the same order as in the original list by pressing an appropriate button on the keypad. Previous pilot work indicated that significant differences in performance resulted from manipulations of the number of words to be retained in memory. Two sets, A and B, of ten words were selected; they were closely matched on values of Imagery and Frequency (Paivio, Yuille, and Madigan, 1968). Mean frequencies were 14.3 per million on list A and 13.9 per million for list B while mean Imagery values (on a 7 point scale, 1 being low in imagery) were 2.86 for list A and 2.91 for list B. Two sets were used to insure that no list specific effects arose during the experiment. The orders of the words in the target lists were selected at random by the program as were the words to appear in the comparisons and their orders.

The spatial main task is a modification of one developed by Chiles, Alluisi, and Adams (1968). In this task, a histogram comprised of either 2 or 6 bars appeared upside-down. Subjects were to mentally rotate this pattern to the upright position and retain it over the retention interval for comparison with a subsequent test pattern. Subjects indicated whether the two patterns were the same or different by pressing an appropriate

button on the keypad. Previous pilot work indicated that the use of 2 versus 6 bars would result in significant differences in performance. Length and configuration of bars in the target was chosen at random by the stimulus generation program. Whether or not the test pattern was the same or different than the target was also determined randomly, as were the lengths and configuration of bars in test patterns that were different. In order to minimize the possible use of verbal coding as a means of retaining the histogram targets, instructions to the subjects stressed that they should use visual imagery to rotate and retain these patterns.

The task embedded in the retention intervals of the two main tasks was a Sternberg (1969) memory search task that employed a fixed memory set procedure. This memory set was displayed to subjects at the beginning of each block of trials. Subjects were then asked to study and learn the set for use later in the block. Memory probes appeared during the retention interval of either the previously described verbal or spatial memory tasks. Subjects indicated whether or not a probe was a member of the set by depressing an appropriate button on the keypad. Letters of the alphabet were used as stimuli and those that made up the set were chosen at random. Each probe was randomly determined to be a member or non-member of the memory set, and the specific letter to be used as a probe was then selected randomly from the appropriate group. Two memory set sizes, 4 and 6, were used to

manipulate the difficulty of the task. Since letters of the alphabet were used as the memory stimuli, this task is considered to be primarily verbal in its processing demands.

Procedure

Dual task blocks began with instructions to the subject about how his attention was to be divided. This was followed by presentation of the Sternberg memory set for a 10 second study period. The set was replaced by a histogram pattern or word list, depending upon what combination was being performed. This target material remained on the screen for a period of 8 seconds. When the target material disappeared, a cross-hair appeared for 1 second to direct subjects' eyes to the point at which letter probes would appear. Probes then began appearing at intervals of 1 second for the duration of the retention interval; each retention interval contained 15 probes. The subject responded to each of these by pressing an appropriate button on the response pad. Failure to respond during a 1000 msec interval was counted as an incorrect response. After completion of the retention interval, a test stimulus appeared. This test stimulus remained on the screen for a maximum of 3 seconds. If no response was given during this time, it was recorded as an incorrect response. As noted previously, subjects indicated whether the test was the same or different than the target by pressing the appropriate buttons on the keypad. The same buttons were used for all three tasks. Each block was made up of 10 trials of the main task and

the corresponding number (150) of letter probes. Figure 3 illustrates the sequence of events in dual task trials; single task trials followed an identical procedure, except that the screen remained blank for the part of the block where the other task would normally have appeared.

Insert Figure 3 about here

Subjects received bonuses for their performance of the tasks, up to a maximum of $.50 per block. This amount was divided between tasks in proportion to the emphasis instructions given prior to the block. Subjects earned the percentage of those amounts on which they met the criteria for the respective task. Generally, criteria were a combination of reaction time limits and percent correct. For example, if task A was to receive 75% attention and a subject met the criteria on 80% of the trials, he earned $.30 of a possible $.375 on task A for that block. For task B, given 25% attention, payoffs were derived in the same manner. Single task trials were treated as a 100% attention condition in the payoff structure. Subjects received feedback after each block of trials consisting of the actual amount earned on each task, the maximum that could have been earned for that task, and the respective totals.

Design

Subjects participated in 3 sessions. Each session was

approximately 2.5 - 3 hours in length. These sessions were conducted at the same time each day, plus or minus two hours. No more than two days elapsed between sessions. The first session was for general introduction and training. Handedness testing and scheduling were accomplished at an earlier time. Days 2 and 3 were used for testing; one day was used for the verbal-verbal combination, the other for the spatial-verbal combination. One-half of the subjects completed one combination on day 2, the other half received the other combination on day 2. Those two groups were halved again, with each half using a different word set. These assignments were made at random.

Four combinations of main and embedded task difficulty (easy-easy, easy-difficult, difficult-easy, difficult-difficult) were used in dual task performance at each of three priority levels: 75% attention to one task and 25% to the other, the reverse, and an equal attention condition. The order of occurence of priority and difficulty manipulations was counterbalanced across subjects. All combinations of difficulty were performed in succession at each priority level to avoid confusion of task emphasis. Before each of the emphasis conditions was performed and at the end of the session, a block of single task trials was presented. These corresponded to the two levels of difficulty for each of the two tasks being performed on that day. The order for these blocks across the test day was determined randomly.

Results

Search task analyses

Mean reaction time for correct responses and percent error were obtained for each block and used in the subsequent analyses. Both error and reaction time data were subjected to a 2 X 2 X 2 X 3 repeated measures analysis of variance representing 2 levels of main task type (verbal vs. spatial), 2 levels each of search task difficulty and main task difficulty (easy vs. difficult) and 3 levels of emphasis instruction (emphasis on the: search task, equal to both, or main task). Effects of interest to the previously made predictions will be addressed.

As predicted, the search task was generally more affected by manipulations made when it was performed in combination with the word list task. Overall, errors were higher and reaction times slower in the verbal-verbal combination than in the verbal-spatial, as can be seen in Table 1. The analysis reflected the difference in errors, $\underline{F}(1,11) = 18.58$, $\underline{p} < .01$, but not in reaction time, $\underline{F}(1,11) = 2.25$, $\underline{p} > .10$.

Insert Table 1 about here

Table 1 also shows a strong effect of the manipulation of search task difficulty for both reaction time, $\underline{F}(1,11) = 24.68$, $\underline{p} < .001$, and percent error, $\underline{F}(1,11) = 40.17$, $\underline{p} < .0001$. In the error data, search task difficulty and main task type interacted,

with more effect of search task difficulty in combination with the word list task, as shown in Figure 4. The effect was statistically reliable, $F(1,11) = 5.51$, $p < .05$. This effect was particularly important to the hypothesis under study as it indicates that competition for resources made the effect of search task difficulty more pronounced in the verbal-verbal combination.

Insert Figure 4 about here

The Wickens (1980, 1984) model and the Navon and Gopher (1979) methodology would both also suggest an interaction between main task type and main task difficulty showing that main task difficulty manipulations produced more effect on the verbal search task when the main task was verbal than when it was spatial. No such interaction was found in either the error or the reaction time data (Fs < 1). The manipulation of task emphasis did have the expected effect, as illustrated in the percent error data in Figure 5. Search task performance deteriorated as subjects were instructed to withdraw resources from it in the verbal-verbal combination but not in the spatial-verbal one. This interaction between emphasis condition and main task type was also significant, $F(2,22) = 5.71$, $p < .01$.

Insert Figure 5 about here

A seperate analysis was performed to examine the single to dual task decrement. This was a 2 X 2 repeated measures analysis of variance, representing 2 levels of main task type (verbal vs. spatial) and condition (single vs. dual). The distinction between the two levels of main task difficulty in the dual task condition is not made here as suggested by Roediger, Knight and Kantowitz (1977). Main task difficulty was collapsed across because of the lack of any effect of main task difficulty on search task performance as demonstrated above. This analysis provides another example of an overall greater deterioration of performance in the search task when it was combined with the verbal main task than with the spatial one. As illustrated in Figure 6, percent errors committed rose dramatically in combination with the verbal main task while not at all when combined with the spatial main task. This interaction between condition and main task type was significant only in the error data, $\underline{F}(1,11) = 13.21$, $\underline{p} < .01$.

Insert Figure 6 about here

<u>Main task analyses</u>

Mean reaction time for correct trials and percent error for

each block were also the dependent variables in the main task analyses. For the two main tasks, manipulations of difficulty for each task in single task conditions had their desired effects, with increases in both reaction time and percent error reflecting the increases in difficulty. Means are shown in the top portion of Table 2. Single factor (difficulty) repeated measures analyses of variance supported the differences, in the spatial main task in both reaction time, $F(1,11) = 7.73$, $p < .01$, and percent error $F(1,11) = 5.67$, $p < .05$, and in percent error in the verbal main task, $F(1,11) = 11.55$, $p < .01$, but not so in reaction time, $F < 1$. The manipulations were also effective in the dual task situation, with increases in reaction time and percent error again being recorded, as shown in the lower portion of Table 2. In single factor (difficulty) repeated measures analyses of variance, the difficulty effect was significant in spatial main task reaction time, $F(1,11) = 21.95$, $p < .001$, and marginally significant in percent error, $F(1,11) = 3.99$, $.05 < p < .10$. In the verbal main task, the effect was significant for both dependent variables, $F(1,11) = 13.83$, $p < .01$ in reaction time and $F(1,11) = 10.45$, $p < .01$ in percent error. An analysis similar to the one carried out on the search task single to dual task data was repeated in examining the same effect in the main tasks. No statistically reliable differences were found (all $p > .10$).

Insert Table 2 about here

As a check on whether the emphasis manipulation might have obscured any single to dual decrement, a 2 (main task type) X 4 (emphasis condition) analysis of variance was performed with single task conditions as one of the emphasis conditions (100%). Percent errors committed did, in fact, rise in the verbal main task as emphasis instruction moved from the 100% condition (18% error) to the 25% condition (34% error). A smaller decrement occured in the spatial main task, as errors again rose from the 100% emphasis condition (12%) to the 25% emphasis condition (17%). This interaction was significant, $\underline{F}(3,33) = 3.82$, $\underline{p} < .01$.

The remaining data from the two main tasks was analyzed in a single ANOVA for interpretation of the interaction of main task type with the effects of search task difficulty and task emphasis. An analysis similar to the one performed on the search task data was performed on the reaction time and percent error data for the main tasks. Only interactions including the effect of main task type were examined so that the predicted differential pattern of effects between these tasks could be examined.

Figure 7 illustrates the interaction of main task type and

search task difficulty for both reaction time and error. As can be seen from the figure, no effect of search task difficulty occured in either measure for the spatial main task, while contrasting effects were found in the reaction time and percent error measures for the verbal variant, reflecting a speed-accuracy tradeoff. The reaction time interaction was reliable, $F(1,11) = 10.72$, $p < .01$, while it was not significant for percent error, $F(1,11) = 3.09$, $p > .10$. The error data reflect the predicted deterioration in verbal main task performance as search task difficulty is increased while the reaction time data reflect the opposite effect. This speed-accuracy tradeoff does not allow clear interpretation of this data. Another predicted effect was that main task difficulty manipulations were predicted to be more pronounced in the verbal-verbal condition over the verbal-spatial one. This effect, as in the search task data, was not found in the data (all $p > .01$).

Insert Figure 7 about here

In the analysis of the emphasis manipulation, the error data again show the predicted effect while the reaction time data show something of the opposite, again showing a tendency for a speed-accuracy tradeoff, as depicted in Figure 8. The interaction of main task type and emphasis condition was significant in the percent error data, $F(2,22) = 4.36$, $p < .05$, but not in reaction

time, $F(2,22) = 1.21$, $p > .10$. As can be seen from the figure, as resources were withdrawn from the search task in favor of the main task, percent error decreased for the verbal main task but remained relatively unchanged in the spatial main task.

Discussion

It was predicted that performance would be generally worse in the verbal-verbal condition than in the verbal-spatial one, and that the former would be more sensitive to manipulations of task difficulties and emphasis than would be the latter. In finding this general pattern of results, this study supports the multiple resources distinction between the verbal and spatial codes of processing.

Overall, the data, especially in the search task, support the distinction made in the Wickens (1984) model between the two codes of processing. When combined with the verbal main task, search task performance was generally worse in dual task and the decrement from single to dual task was greater than when this task was paired with a spatial main task. One argument that might be made against the interpretation of this data in favor of multiple resources theory would suggest that the spatial task was not difficult enough to exhaust all available resources. If this argument were correct, then this study would fail to differentiate between a multiple resources model and the earlier single capacity model (Kahneman, 1973) for the simple reason that the capacity was exhausted in the verbal-verbal combination but

not in the verbal-spatial one. That would explain why interference was found in the former case and not in the latter if there is only a single capacity. While this argument cannot be ruled out entirely in the present study, it is weakened considerably by the fact that the difficulty manipulation significantly affected single task performance on the spatial main task. This suggests that allocation of more resources or capacity to maintain performance on the spatial task is not a likely explanation of the lack of interference in this condition. Given this demonstration of an effect in single task conditions, it appears somewhat difficult to argue that the same manipulations of difficulty would not be effective in exhausting resources in the perhaps more sensitive dual task situation.

There are other factors to consider, however. For one, the failure to find any effects of main task difficulty in search and verbal main task performance. The prediction was made that if both verbal tasks drew from the same pool, that main task difficulty manipulations would result in greater deterioration in search task and verbal main task performance in the verbal-verbal condition than in the verbal-spatial one. Such interactions were not present in the data. The fact that there was significant trading of resources, that is, an effect of emphasis instruction, and the fact that the difficulty effect was absent in both tasks does not allow the argument that subjects were somehow protecting performance on one of the tasks. In the

search task, one explanation may be that some ceiling or data limit was reached in search task performance. It may simply be that performance could get no worse. Evidence to support this explanation is difficult to find in the literature, since subjects are generally instructed to keep errors to as low a number as possible on tasks such as these (Sternberg, 1969; Pachella, 1974). The single task percent error data are in keeping with the usually accepted levels for this task (see Figure 6). Another explanation might be that the subjects, who were instructed to be as fast as possible while being as accurate as possible, would not allow the error level to rise any higher. It is also notable, given these instructions, that the error data was generally more sensitive to these effects than reaction time data, though the reaction time data for this task did show the predicted trend. Perhaps interference between the two verbal tasks had an effect similar to that of retroactive interference, causing loss of part, but possibly not all, of the memory set. This would cause a rise in error levels but would not necessarily cause a great change in reaction time. In fact, given that the size of the memory set might now be smaller, one might even expect a faster reaction time.

Single to dual task comparisons, in contrast, were indicative of a greater degree of interference in the verbal-verbal condition than in the spatial-verbal one. It was pointed out earlier that Roediger, Knight and Kantowitz (1977) argued

against the utility of this comparison in judging capacity types of interference. Certain aspects of their argument are not as valid in the present work, however. Input-output interference, which they argued could also explain the single to dual decrement finding, was minimized here. Also, any interference that occured in one combination should also have been present in the other since both used identical procedures. The same argument applies to their concern about an increase in executive control in the change from single to dual task conditions. Again, equal or nearly equal degrees of control should have been required in both conditions, nullifying this factor as an explanation for these findings. While the concerns addressed by Roediger et al are certainly valid, they may be less so here because of the design of this study.

The absence of predicted interactions with the manipulation of main task difficulty, though important, does not determine the success or failure of the Wickens (1980, 1984) approach. Navon and Gopher (1979) argue that finding the effect of a difficulty manipulation in only one of the tasks in a dual task condition is still strong evidence that resources are being competed for. Also, a point central to multiple resources argument is that no single experiment or combination of tasks will reveal the whole structure of the multiple resources system. Navon and Gopher (1980) point out that a number of different tasks and task combinations will be required to fully establish the multiple

resources framework as a useful theory. It is from this consideration that the logical follow-up to this experiment comes. Using a spatial version of the memory search task, one should find the opposite pattern of results. That is, if the model holds, more interference should be present in the spatial-spatial combination than in the spatial-verbal one. Sperling (1984) argues that this demonstration using several tasks and combinations is the strongest argument for multiple resource theory. With that kind of data to complement the current work, the Wickens (1984) model would receive a great deal of support for the spatial-verbal dimension. The utility of this finding is obvious. In situations where the amount of load on an operator is important, competition between these two codes should be kept to a minimum.

A final consideration is the recent criticism that has been leveled at multiple resources theory (Navon, 1985). Two points seem especially important in regard to the present work. One, Navon (1985) argues that one methodological problem in the multiple resources approach is that experimenters may convey to subjects that two tasks will trade resources simply by asking them to emphasize one over the other, thus creating an artifact. The current work does not seem entirely consistent with that assertion. In both the verbal-verbal condition and the verbal-spatial condition, subjects were given identical emphasis instructions and payoffs were formed in identical fashion. The

experimenter was not naive, but the emphasis instructions before each block and the feedback afterward were given in standard fashion across combinations. If Navon's argument is correct, then trading should have occured in both conditions; it occured only in the verbal-verbal combination, however. There is no reason within Navon's argument for this to have happened. Without making the error of accepting the null hypothesis, the pattern found in the current work certainly does not support the suggestion that subjects' performance reflected a response to an artifact in the emphasis manipulation.

A second major point in the Navon (1985) argument is quite simply that the multiple resources explanation of the attention phenomena may not be the best one. He argues that the multiple resources notion is inadequate because there are other alternatives that can account for the data without the notion of resources. He offers a possible alternative, namely "outcome interference," the general idea being that tasks interfere not because of resource competition but instead because the concurrent activities produce "side-effects" that may be harmful to performance. This idea seems quite similar to one proposed by Kinsbourne and Hicks (1978) in which interference is predicted on the basis of how closely two activities are carried on in the cerebral space. It may be difficult for such a notion to handle the trading relationship observed in the current work without relying on the artifact argument discussed above. There is no

other reason within such a conceptualization for a trading relationship to exist except to assume that one task is interrupted, temporarily or permanently, in favor of the other one. The present work does not provide a basis for a decision on that argument.

To conclude, then, the Wickens (1984) model was generally supported by the data gathered in this investigation. Arguments against the multiple resources approach do not seem to significantly weaken the conclusion that spatial and verbal codes require seperate resources. The logical complement to this investigation will provide an even greater context within which to interpret results of the current investigation.

Table 1

Mean reaction time and percent error in the memory search task as a function of main task type and memory set size.

	Dependent Variable	
Effect	RT (msec)	Percent error
Main task type		
Verbal	550.93	15.4
Spatial	542.44	9.8
Memory set size		
4 letters	532.70	9.4
6 letters	560.70	15.9

Table 2

Mean reaction time and percent error in single and dual task conditions as a function of difficulty manipulations in main tasks.

Effect	RT (msec)	Percent error
	Dependent Variables	
Single task condition		
Verbal main task		
4 words	1893.9	7.5
8 words	1922.4	29.1
Spatial main task		
2 bars	1059.4	5.8
6 bars	1205.5	17.5
Dual task conditions		
Verbal main task		
4 words	1555.3	22.8
8 words	1740.0	33.3
Spatial main task		
2 bars	1057.1	12.6
6 bars	1189.9	17.8

Figure captions

Figure 1 Wickens model of multiple resources, with the dimension under study in the current investigation highlighted (used with permission).

Figure 2 Experimental tasks and their combinations.

Figure 3 Sequence of events in dual task blocks.

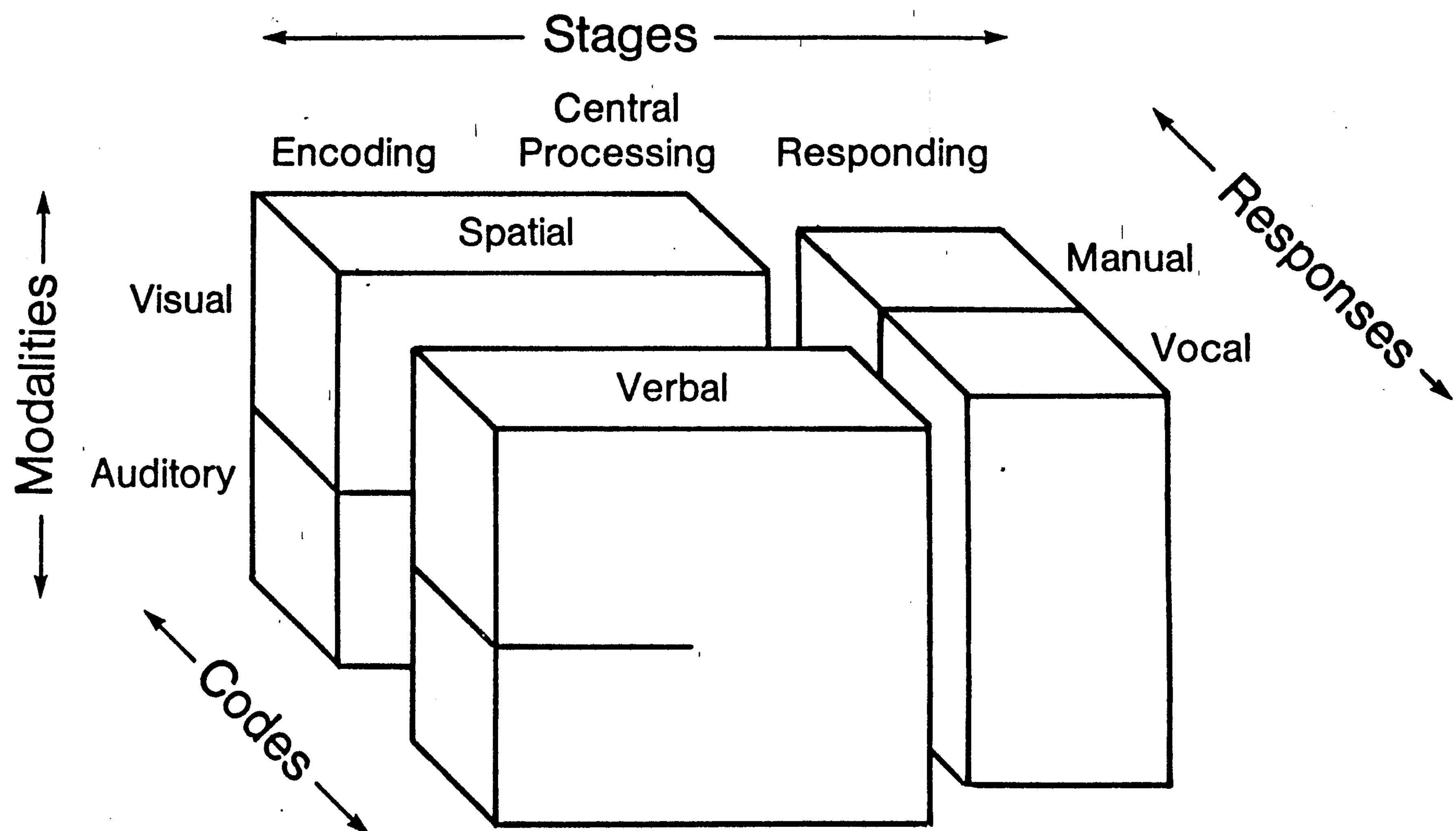
Figure 4 Percent error in the search task as a function of search task difficulty and main task type.

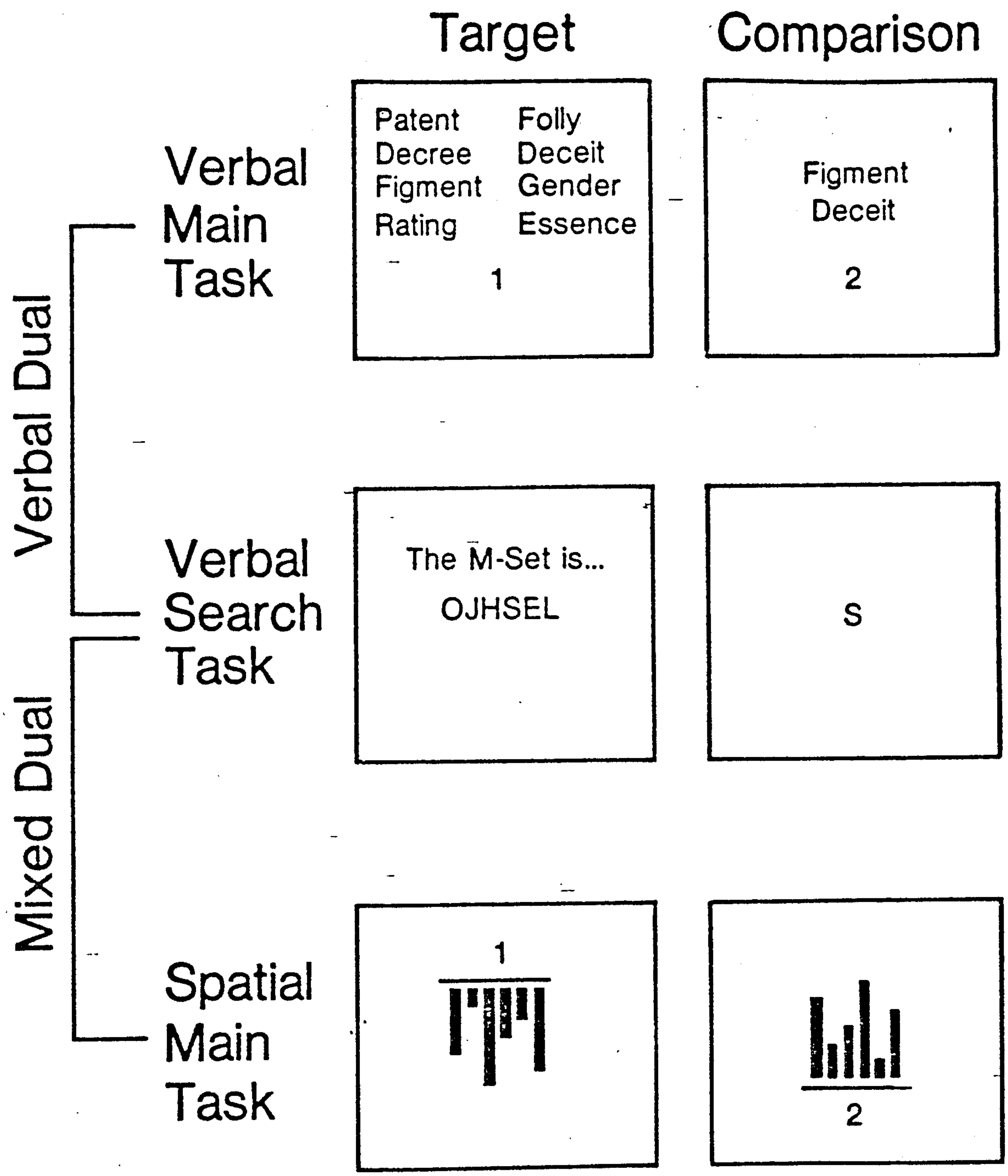
Figure 5 Percent error in the search task as a function of task emphasis and main task type.

Figure 6 Percent error in the search task as a function of single vs. dual task and main task type.

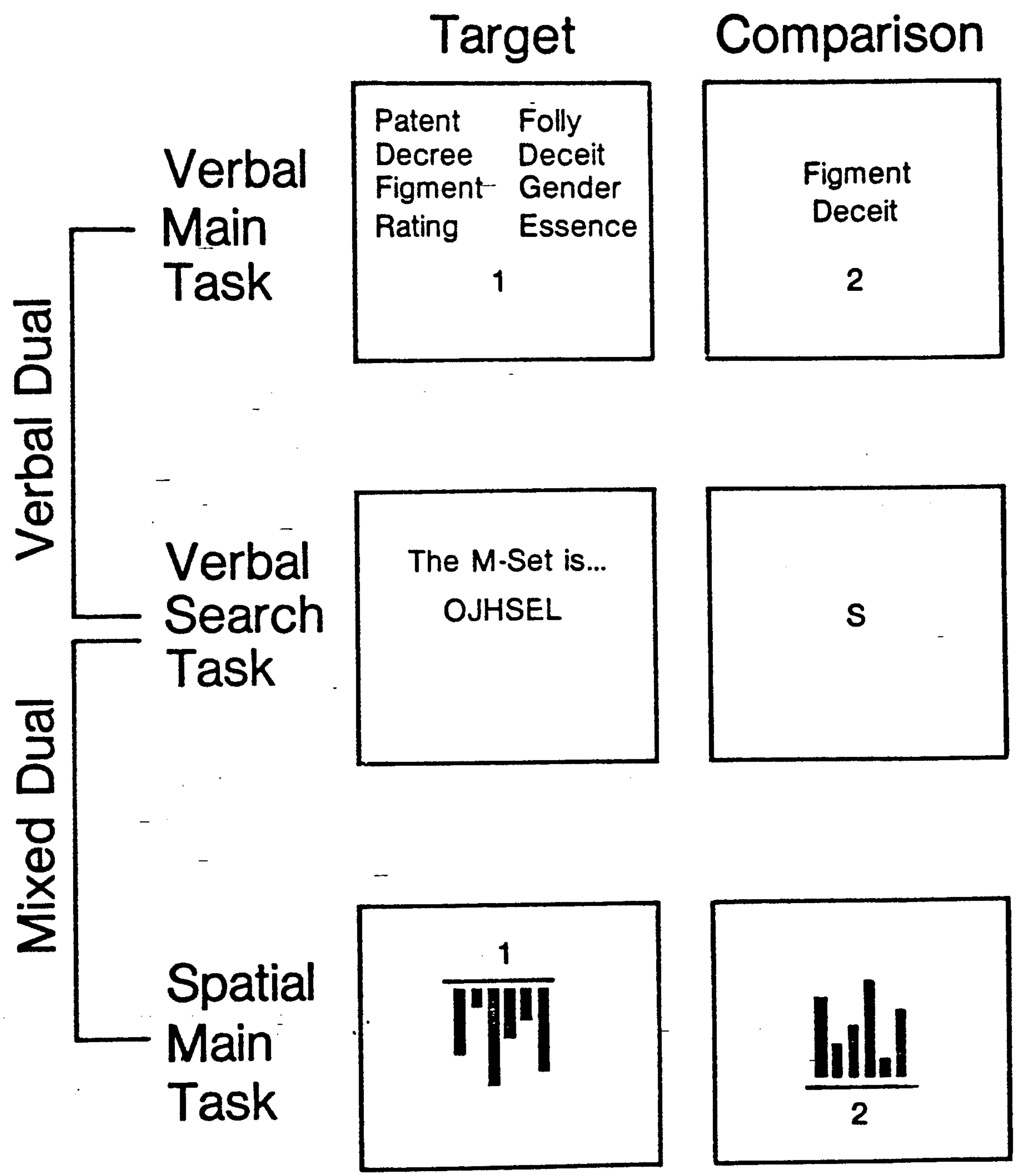
Figure 7 Mean reaction time and percent error for main tasks as a function of search task difficulty and main task type.

Figure 8 Mean reaction and percent error for main tasks as a function of emphasis and main task type.


Stages
Encoding
Central Processing
Responding
Responses
Modalities
Visual
Auditory
Spatial
Verbal
Manual
Vocal
Codes



Target
Comparison
Verbal Main Task
Patent
Decree
Figment
Rating
Folly
Deceit
Gender
Essence
1
Figment
Deceit
2
Verbal Dual
Verbal Search Task
The M-Set is...
OJHSEL
S
Mixed Dual
Spatial Main Task
1
2


Target
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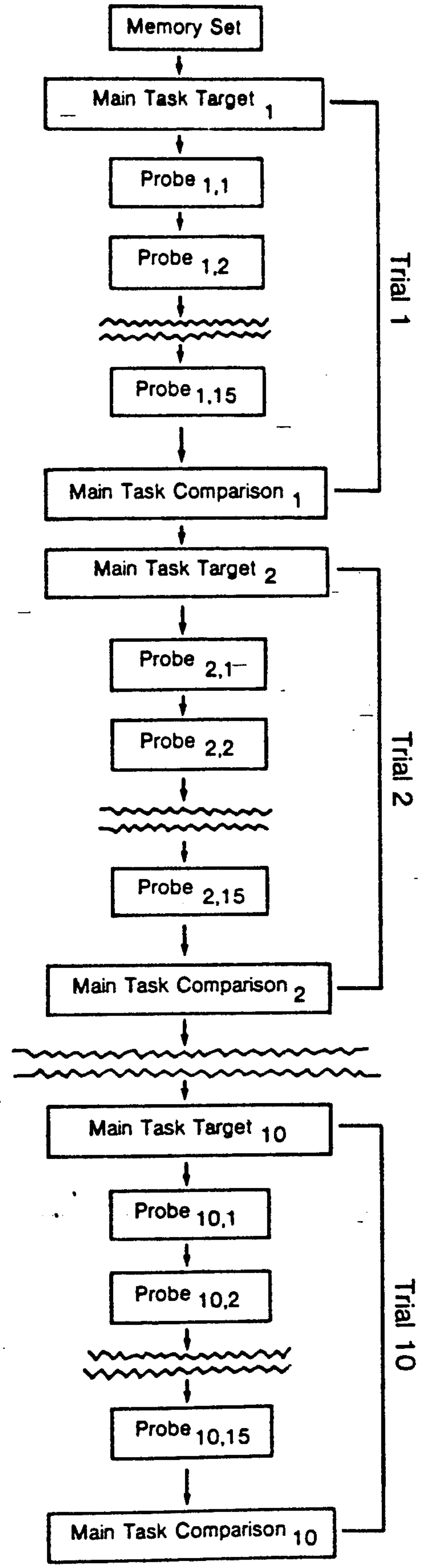
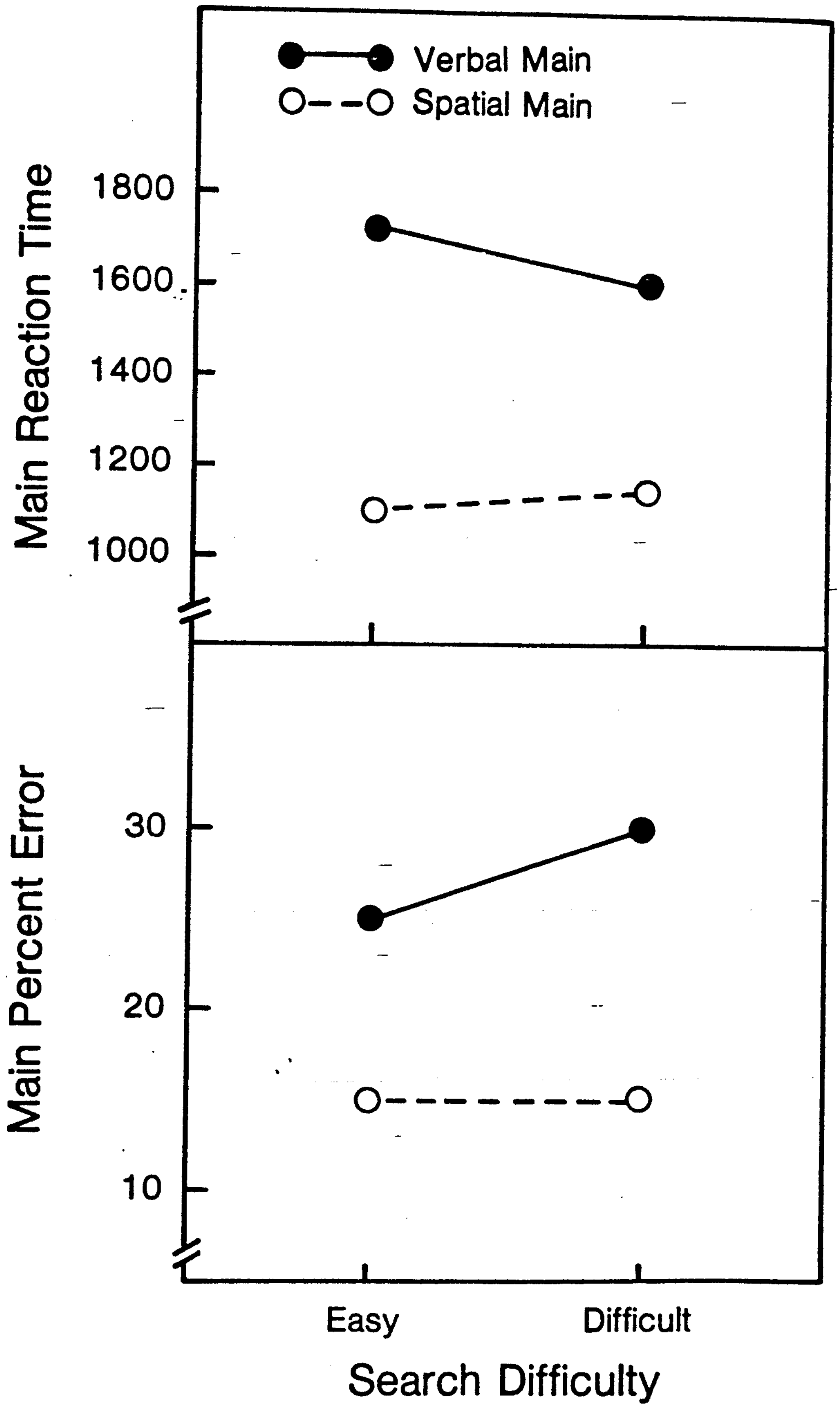
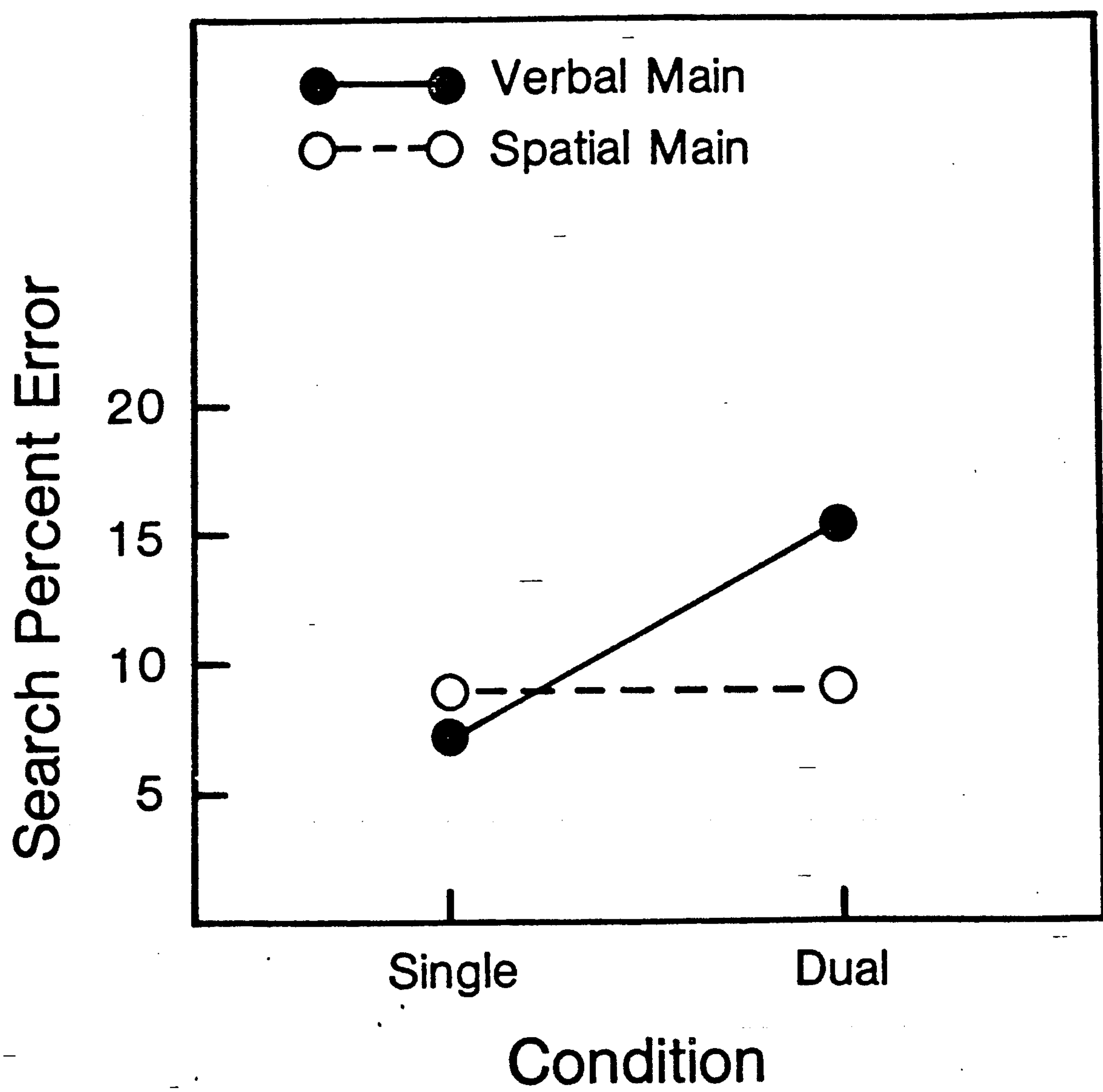
Verbal Dual
Verbal Search Task
The M-Set is...
OJHSEL
S
Mixed Dual
Spatial Main Task
1
2


Memory Set
Main Task Target 1
Probe 1,1
Probe 1,2
Probe 1,15
Main Task Comparison 1
Trial 1
Main Task Target 2
Probe 2,1
Probe 2,2
Probe 2,15
Main Task Comparison 2
Trial 2
Main Task Target 10
Probe 10,1
Probe 10,2
Probe 10,15
Main Task Comparison 10
Trial 10



Verbal Main
Spatial Main
Main Reaction Time
1800
1600
1400
1200
1000
Main Percent Error
30
20
10
Easy
Difficult
Search Difficulty



Verbal Main
Spatial Main
Search Percent Error
20
15
10
5
Single
Dual
Condition